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Preface

This paper considers a real world problem of determining the appropriate logistics strategy for a Norwegian sewage collection company to collect sewage in the municipality of Melhus. The company owns two different types of trucks with trailer for sewage collection, one of the logistics strategies to collect sewage is to use only traditional truck to drive the tour, while the other is to use both traditional truck and dewater truck to serve the customers. When using traditional truck, the number of septic tanks that can be emptied in one trip is smaller than that when using de-watering truck, this means that the traditional truck has to drive to the sewage plant for emptying the collected sewage water more frequent than using the de-watering truck, and thus the driving distance for the truck will be higher. On the other hand, when using dewatering truck, it needs to drive extra 75 km from the sewage plant to the sewage treatment plant for each tour. With the aim to identify the economic sustainability and key impacts related to climate change, this paper will help the Miljøservice AS company to identify the proper logistics strategy for sewage collection and propose several suggestions regarding allocation of different types of vehicles for serving varying districts within Melhus in order to reduce the driving cost as well as the emission of pollution gas. The program of CoordTrans will be applied to position and cluster customers. And the total driving distance for serving each cluster of customers under different logistics strategies will be calculated in order to identify the proper logistics strategy.

Keywords: Sewage Collection, Logistics Strategy, CoordTrans, Cluster, Driving Distance

Summary

By comparison of the total driving distance under different logistics strategies for sewage collection, we can conclude that the strategy using both traditional truck and dewatering truck to serve the customer is superior to the other strategy using only traditional truck, since the corresponding total driving cost and the the total amount of emission produced by vehicles are lower than the other strategy.

Thus, it is quite necessary for the company to implement the logistics strategy using both two types of truck to serve the customers.

Contents

1. Introduction

This paper is concerned with sewage collection problem, which can be classified as a waste collection problem. Beltrami and Bodin (1974) described the municipal waste collection problem in New York City, where daily solid waste collection are 25,000 tons, and the New York City Department of Sanitation needs to solve the problem of scheduling the garbage trucks for waste collection. In this problem, most of the sites need to be visited three times in a week; Monday, Wednesday, Friday, and a small number of sites need to be visited six times per week. To solve this period Vehicle Routing Problem (VRP), they clustered and scheduled the sites first, then routed the vehicles for waste collection. Tan and Beasley (1984), and Chao, Golden, and Wasil (1995) also have studied for this period VRP, they address this problem by proposing several heuristics.

Septik24 is a network of environmental corporations in Norway, mainly offering services regarding collection, dewatering and transportation of septic sludge, making great contribution to green business in Norway. More than 150 Municipalities make use of their modern sludge evacuation and dewatering technology for obligatory sludge removal. Septik24 consists of the companies of Miljøservice AS, Hoston Miljøservice AS, Miljøkompost AS, and Johny Birkeland Transport AS.

Miljøservice AS, Hoston Miljøservice AS and Johny Birkeland Transport AS mainly focus on the business of collection, dewatering of septic sludge, and management of sludge disposal for municipalities, while the main business of Miljøkompost AS is to compost septic sludge collected from septic tanks. In this paper, we will only discuss about sewage collection performed by the company of Miljøservice AS.

The company Miljøservice AS starts to perform the sewage collection in the municipality of Melhus in 2013. Around 1835 customers in this municipality require sewage collection every 52 weeks or 104 weeks. The current logistics strategy proposed by Miljøservice AS for sewage collection in Melhus is to use only one traditional truck to drive the tour. In addition, the other strategy using both one dewatering truck and one traditional truck for sewage collection is possible to perform. The company wants to identify the proper logistics strategy to serve the customer in order to reduce the total driving cost and the emission of pollution gas. Figure 1 shows the geographic location of the sewage plant in this municipality.

Figure 1. The municipality of Melhus in Sør-Trøndelag county with sewage plant marked

The green circle indicates the position of sewage plant in Melhus. The customers attached with the septic tank are scattered throughout the municipality. Normally, each septic tank needs to be cleaned up every 52 weeks or 104 weeks, and each septic tank has certain amount of sewage in volume (liters).

The company Miljøservice AS has a fleet of heterogeneous vehicles with or without trailers for sewage collection. Drivers are limited by hours in a working day. When the truck is fully loaded on the tour, it must drive back to the sewage plant for emptying the sewage. Each truck can drive several routes per day. The vehicles used by the company can be classified as traditional truck and dewater truck. When using the traditional truck, the content (sewage) in the septic tank will be vacuumed into the truck tank, when the tank is filled up, the content will be transported to a stationary sewage plant for emptying the tank, if there is time available, the traditional truck will continue a new tour starting and ending at the same depot (sewage plant). When using the dewater truck to clean the septic tanks, the sludge will be dewatered directly in the truck tank, then the rejected water will be pumped back into the biological septic tank, and afterwards, the separated sludge will be transported to a sewage treatment plant, approximately 75km far away from sewage plant, for further treatment. Generally, the company allocates traditional truck to serve those customers near the sewage plant, while customers further away from the sewage plant could be served by the dewater truck.

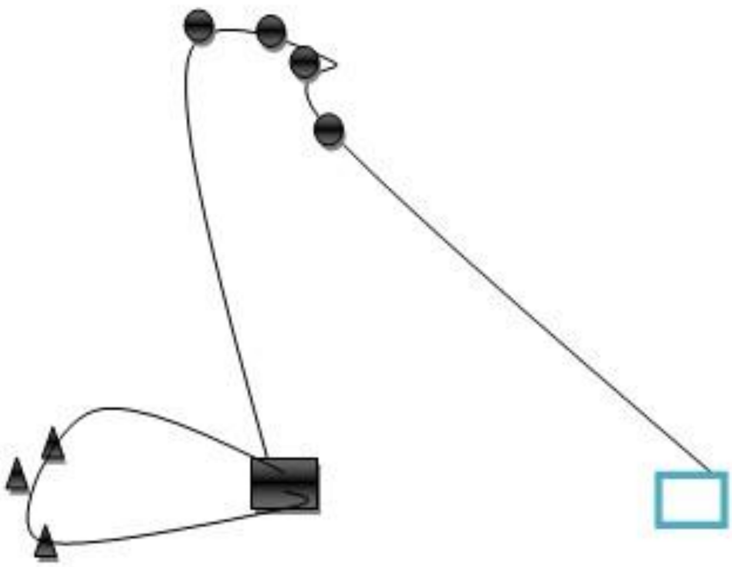

Figure 2. The structure of solution for sewage collection used by Miljøservice AS

Figure 2 represents the general solution used by Miljøservice AS for sewage collection mentioned above. The square on the left marks the depot (sewage plant) for the traditional truck, while the triangles closed to the square are those customers served by the traditional truck. The square on the right indicates the depot (sewage treatment plant) for the dewater truck; while the circles represents those customers far away from the sewage plant, and can be visited by the de-water truck. When using traditional truck, the number of septic tanks that can be emptied in one trip is smaller than that when using de-watering truck, this means that the traditional truck has to drive to the sewage plant for emptying the collected sewage water more frequent than using de-watering truck, and thus the total driving distance for the truck will be higher. On the other hand, when using dewatering truck, it needs to drive extra 75 km from the sewage plant to the sewage treatment plant for each tour.

The Pollution Control Act (Act of 13 March 1981 No.6 Concerning Protection Against Pollution and Concerning Waste, 2003) is the regulation in Norway to protect the outdoor environment against pollution to reduce existing pollution, to reduce the quantity of waste and to promote better waste management. According to this Act, the municipality and the waste collection company should be responsible to dispose sludge and waste water properly from collection process to treatment of the septic sludge, in order to ensure pollution and waste do not affect human health.

Miljøservice AS takes the Pollution Control Act into consideration to improve the quality of service, and want to implement the appropriate logistics strategy to collect sewage in Melhus, aiming to reduce the total driving cost as well as the total amount of emission of pollution gases such as Nitrogen Oxide (NOX) and Carbon Dioxide (CO2) related to climate change. In this paper, the objective is to help the Miljøservice AS Company to identify the proper logistics strategy for sewage collection in order to reduce the driving cost as well as the emission of pollution gas.

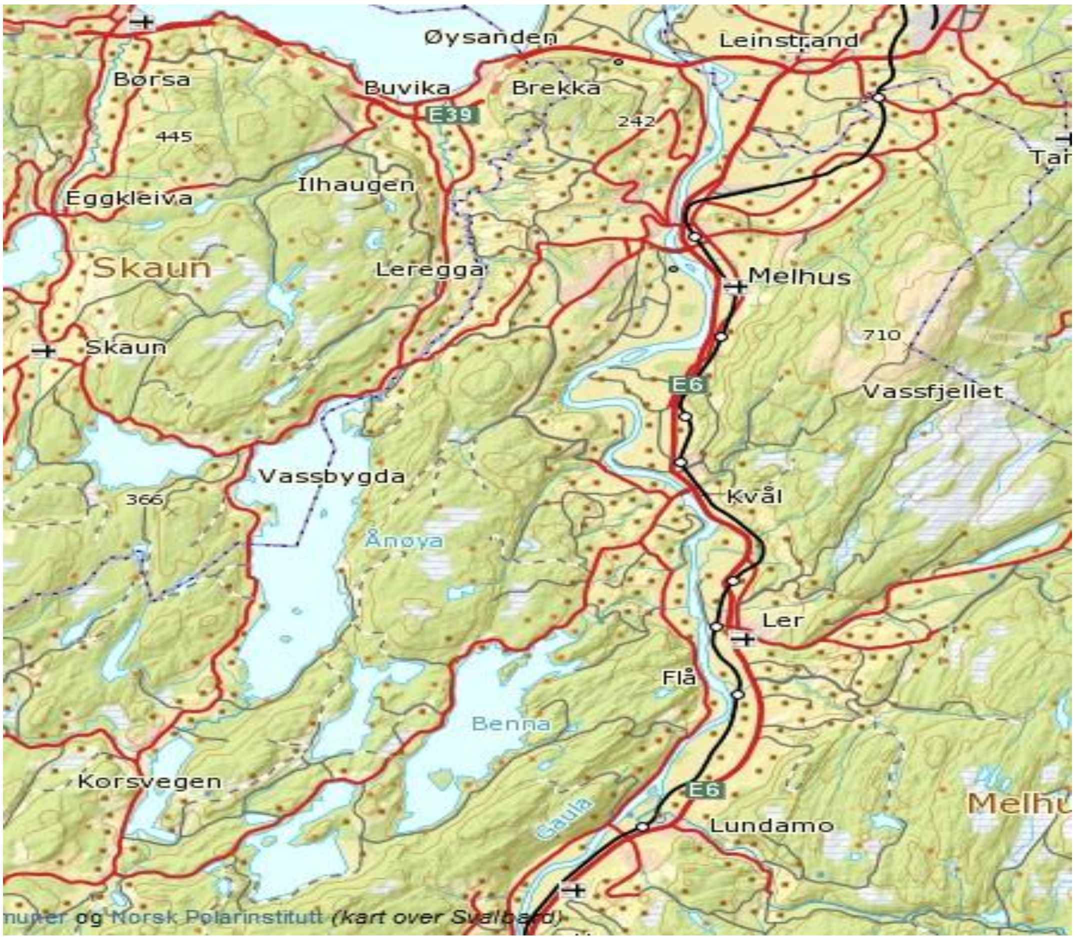

Figure 3. The road map in Melhus

Figure 3 shows the road conditions in Melhus. There isn't any fjord in this municipality, therefore, to drive from one visiting point to another is always reachable by truck. In this paper, Euclidian distance, which considers the direct line between two points i.e. using Pythagoras formula, will not be used, because in really world the exact distance considering hills, curves of roads, and other conditions, between two visiting points will be larger. A distance table, which is the real life distance between different locations, is used to calculate the driving distance in this paper.

This rest of the paper is organized as follows. The related literatures will be reviewed in Section 2, followed by the detailed definition of the problem in Section 3. In section 4, we will discuss about construction of clusters of customers, in addition, methods to calculate the total driving distance under different logistics strategies will be developed. Section 5 shows the computational results, and the conclusion is given in Section 6.

2. Literature review

Golden, Assad, and Wasil (2002) classified waste collection problem as three major types: Commercial, Residential, and Roll-on-roll-off. Commercial collection involves point-to-point collection in a residential network, and the visiting sites are spread throughout the geographic location. In this paper, sewage collection problem can be characterized as a Commercial waste collection problem, service is required at selected 1835 customers in Melhus, and there are two depots (sewage treatment plant and sewage plant) available.

The sewage collection problem in this paper is also similar to other problems. Capacitated Vehicle Routing Problem (CVRP) was first introduced by Dantzig and Ramser (1959). Toth and Vigo (2002) describe that in the CVRP, the demand of each delivery point is predetermined, and the fleet consists of homogeneous vehicles with identical capacity. The objective is to minimize the total driving cost for serving all of the customers. Classical Vehicle Routing Problem heuristics such as Clarke and Wright saving procedures (1964), the Fisher and Jaikumar (1981) algorithm, and Insertion procedures proposed by Christofides, Mingozzi, and Toth (1979) can be applied to give good solutions. To get better solution, metaheuristics such as Osman’s (1993) Simulated Annealing Algorithm, Osman’s (1993) Tabu Search Algorithm, and Ant systems method proposed by Colorni, Dorigo, and Maniezzo (1991) can be used.

Nag, Golden and Assad (1988) consider the Site-Dependent Vehicle Routing Problem (SDVRP), which is a node routing problem. In this paper, the company owns a fleet of vehicles with different capacity and size. For those customers with high demand, the company usually uses high-capacity vehicles to visit, while customers in those areas with bad traffic conditions require small size vehicle to visit. The author proposes several heuristics to give good solution for this problem.

Sniezek, Bodin, Levy and Ball (2002) describe the Capacitated Arc Routing Problem with Vehicle-Site Dependencies(CARP-VSD), which is similar to the SDVRP. In the CARP-VSD, the authors define each set of identical vehicles as a vehicle class; in addition, the constraint that imposes a vehicle from a vehicle class to traverse the street needs to be set because of some limitation like road condition. To solve the CARP-VSD, effective approaches are proposed for solving the partitioning aspect of the CARP-VSD, and then by integrating with the travel-path-generation procedures, the authors derive the Vehicle Decomposition Algorithm (VDA) for solving the CARP-VSD.

Golden, Assad, Levy, and Gheysens (1984) introduce the heterogeneous fleet vehicle routing problem (HVRP), which is also called the fleet size and mix VRP. The objective is to develop a set of minimizing cost routes starting and ending at a depot for serving customers with certain amount of demand, when using a heterogeneous fleet of vehicles. The HVRP involves the assumption that there is no limitation for the number of different types of vehicles, and the cost for all types of vehicle is uniform. By proprosing several heuristics and using approaches to generate a lower bound, an underestimate of the optimal solution is worked out.

Gendreau, Laporte, Musaraganyi, and Taillard (1999) consider the HVRP with variable cost, which is dependent on the vehicle type. In this paper, they develop a tabu search heuristic, giving high-quality solutions for this problem.

Different from the typical CVRP, the sewage collection problem in this paper will not involve the routing problem, but just considers the vehicle allocation problem with the purpose to identify the proper logistics strategies for serving customers.

3. Problem definition

The problem in this paper can be defined as a problem of determining the appropriate logistics strategy for a Norwegian sewage collection company to collect sewage in Melhus. Since the septic tank attached to the customer does not need to be cleaned up every day, the same truck can drive different tours for different days. When using traditional truck, it will drive the tour, starting and ending at the sewage plant, while the dewater truck drives the tour, originating from the sewage plant and terminating at the sewage treatment plant. A dewater truck can clean more septic tanks than a traditional truck in one tour. However, when using dewater truck, it needs to drive extra distance at approximately 75 km to visit the treatment plant for each trip, and in addition, the dewater truck will consume polymer as an additive to dewater sewage, which would cause emission, but in this paper, we will not discuss the emission from the polymer.

Since not all information is known in this paper, some assumptions should be set to make this problem solvable. First of all, the associated time window for serving each customer will not be considered. Secondly, we assume that the fuel cost is the only cost in this paper, then the total amount of consumed fuel can be calculated by dividing the total driving distance by average fuel consumption per kilometer (litres/km).

To calculate the emission of pollution gas, we need to make the assumption that the major exhaust emissions with environmental impact are Hydrocarbons(HC), Carbon Monoxide(CO), Carbon dioxide(CO2), Nitrogen oxides(NOx), and Particulate matter(PM). According to the document of Environmental Product Declaration (EPD) provided by Scania Company, we get the following information regarding the emission factor for the engine of the truck.

Emission factors (g/litre fuel), standard diesel						g/litre Urea**
EURO	NOx	PM	HC	CO	CO_2	CO_2
Euro5, 16-litre	6	0.08	0.13	1.5	2700	260

Figure 4. The emission factor of the engine DC1619 for the truck used by the company

By multiplying the total amount of consumed fuel with the emission factors in Figure 4, we can get the associated total amount of emission of pollution gas produced by the vehicle.

For example, a truck have transported a cargo of 17 tonnes for a distance of 2500 km and have used 867 litres of diesel with a Euro 5-engine. To calculate how much NOx emissions were produced during the transport operation, we can look in the Figure 4 for NOx and get Emission factor of 6 g NOx/litre fuel:

6 g NOx/litre x 867 litre = 5202g NOx =>5.202 kg Nox

Apparently, the total amount of emission is proportional to the total amout of driving distance, it means that the less distance truck drives, the less emission it produces. Thus, to determine the appropriate logistics strategy for sewage collection, we can simply use the approximate total driving distance under different logistics strategies to evaluate the performance of each logistics strategy, and it is not necessary to compute the associated total amount of emission of pollution gas produced during the transport operation.

The detailed definition of the problem can be presented as follows:

1. The problem includes two depots, one is the sewage plant, the other is the sewage treatment plant.
2. The fleet used by the company consists of one traditional truck and one dewater truck.
3. There are two logistics strategies for sewage collection. One is to use only one traditional truck with trailer to serve the customer, and the other is to use both one traditional truck and one dewatering truck with trailer to visit the customer.
4. The capacity for traditional truck with trailer is 30 liters, while the capacity for dewater truck with trailer is 250 liters.
5. There are 1835 customers attached with septic tanks required to be visited.
6. The route driven by the traditional truck starts and ends at the sewage plant, while the route driven by the de-water truck originates from the sewage plant and terminates at the sewage treatment plant with extra 75 km driving distance for each tour.
7. During a two-year period, the frequency to visit the customer is every 52 weeks or 104 weeks.
8. A distance table can be used to calculate the distance between two visiting points and the distance between the depot and each visiting point.
9. The capacity of the vehicle should not be exceeded on the tour. If the total load exceeds the truck's capacity, then the truck needs to drive back to the depot for emptying the tank.
10. The purpose of this paper is to identify the proper logistics strategy for sewage collection in Melhus in order to reduce the driving distance.

In order to make the problem solvable, the following assumptions should be made:

11. The emission factor of engine for both types of truck is relatively equal.
12. The company only uses one vehicle to drive the tour each day.

13. Each customer is assumed to be served by exactly one vehicle.
14. The fuel cost is the only cost in this paper, and the average fuel consumption per kilometers for both two types of vehicle is assumed to be the same.
15. The driving time or the time-dimension for serving each customer is not considered in this paper.
16. Restriction on vehicles to drive on the road network is not involved in this paper.

4. Clustering of customers.

There are 1835 customers attached with septic tanks required sewage collection service from the company. For those tanks called "Gråvannstank", "Pumpekum", "Renseanlegg" and "Slamavskiller", it is arbitrary to use the traditional or dewater truck to clean, while for those tanks named "Tett anlegg", it should be cleaned up by old technology-traditional truck.

In order to reduce the size of the problem, we can develop several clusters for different customers or locations in Melhus, each clustering has certain amount of sewage required to be collected every 52week or 104 weeks.

Gillett and Miller (1974) propose the sweep algorithm to construct the cluster. They describe that feasible clusters can be created by the following steps:

a. Turning a ray centered at the depot clock-wise, and makes a sequence of nodes as the ray sweeps over the nodes.
b. When the capacity of the vehicle is exceeded, it will drive back to the depot.
c. Repeat step a until all customers are visited.

Since the size of the problem is fairly large, using sweep algorithm to construct the clusters is really time consuming, and not possible to finish within limited time. Then we can't use the sweep algorithm to form the clusters.

Another possible approach to form the clusters is to define the sewage collection problem as a CVRP, then we can get the optimal routes by running the programming based on the mathematic model of the CVRP with given data. However, the input data in this problem is more than one thousand, to run the programming in computer to compute the final solution will spend hundreds of years, thus, we should consider other better methods to develop the clusters.

4.1 Construction of clusters

With the coordinate date provided by the company for each customer, we can use the program of CoordTrans to plot each customer on the map. The map of Melhus with customers marked is shown in Figure 5.

The black circle indicates the position of the sewage plant, while the red dots scattered throughout Melhus mark the position of the customers.

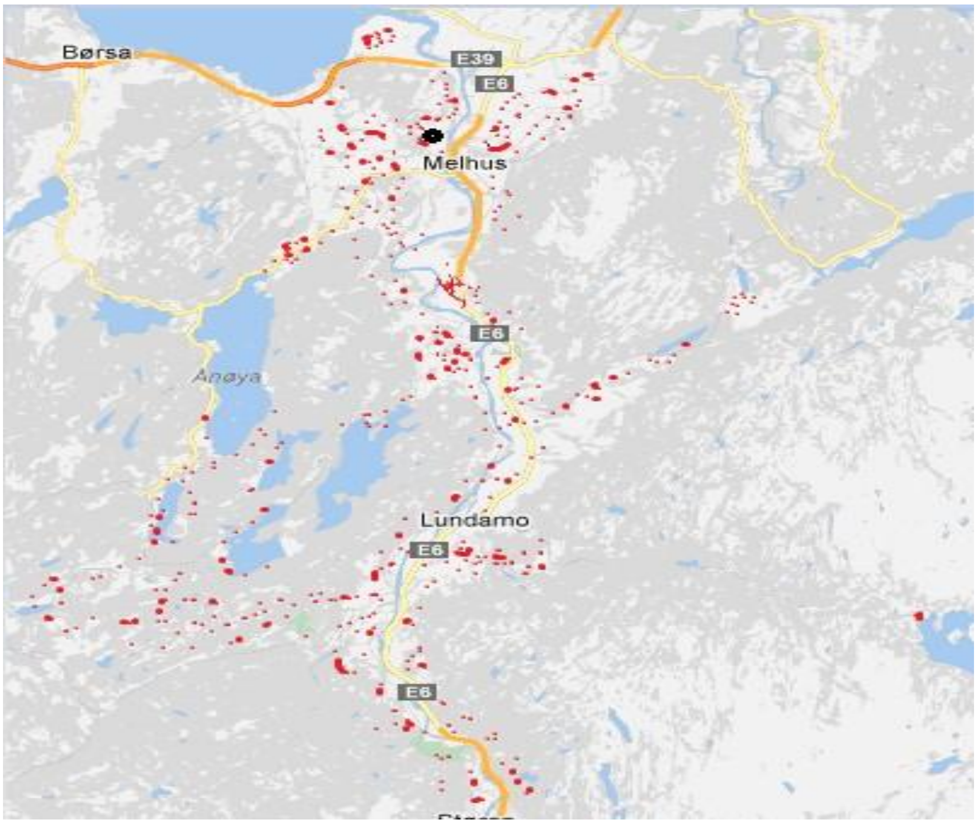

Figure 5 The map of Melhus with depot and customers marked

Based on the given coordinate date as well as the map of Melhus with customers marked, clusters can be developed by the following steps:

1. Grouping those customers with nearby coordinate into several sets in Excel. The reason is that in the real life, the vehicle generally serves those neighboring customers on one tour. This is to reduce the total driving distance and the duration of the routes. A simple illustration is shown in Figure 6.

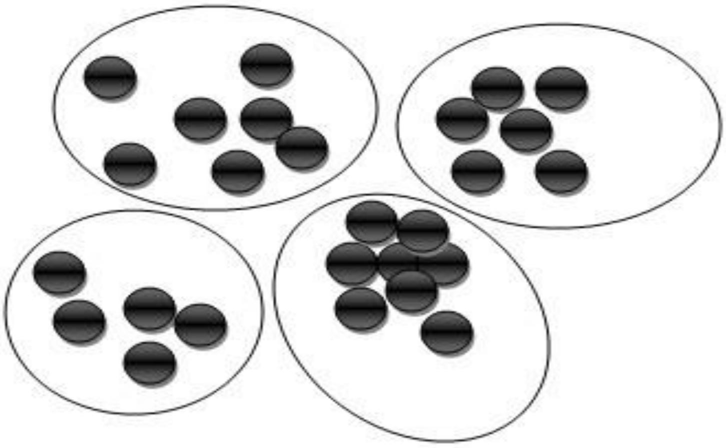

Figure 6 Method of grouping customers

2. Plotting all of the sorted groups of customers on the map. In Figure 7, the circle indicates the sorted groups of customers

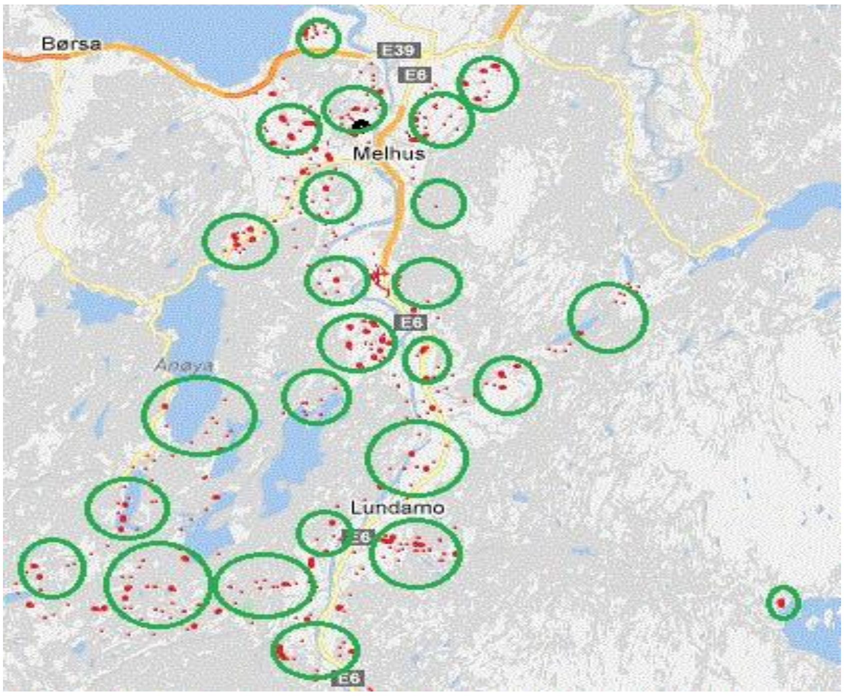

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Figure 7 The map of Melhus with all of the sorted groups of customers marked

3. For those nearby groups of customers located at the same street or road, we can group them as a cluster; a simple illustration is given in Figure 8. The curve represents the road or street surrounded by customers.

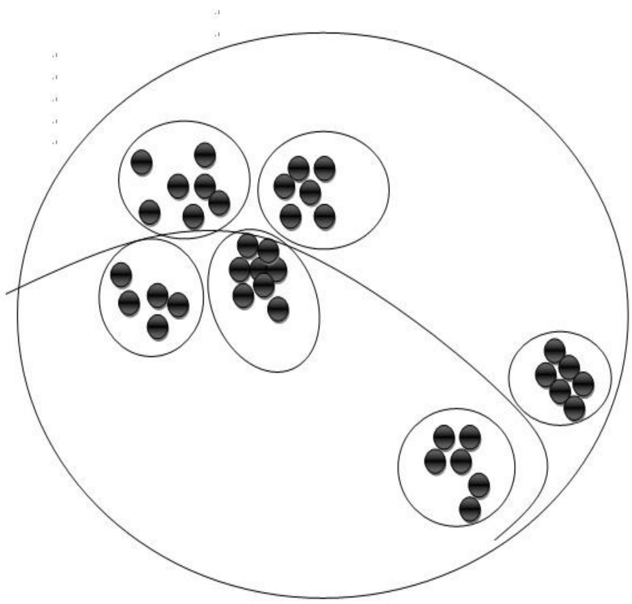

Figure 8 Method of clustering

4. In some districts, only a few customers need to be visited, then we can define those customers located in the nearby cluster area. Figure 9 shows the illustration. The black circle indicates the cluster area.

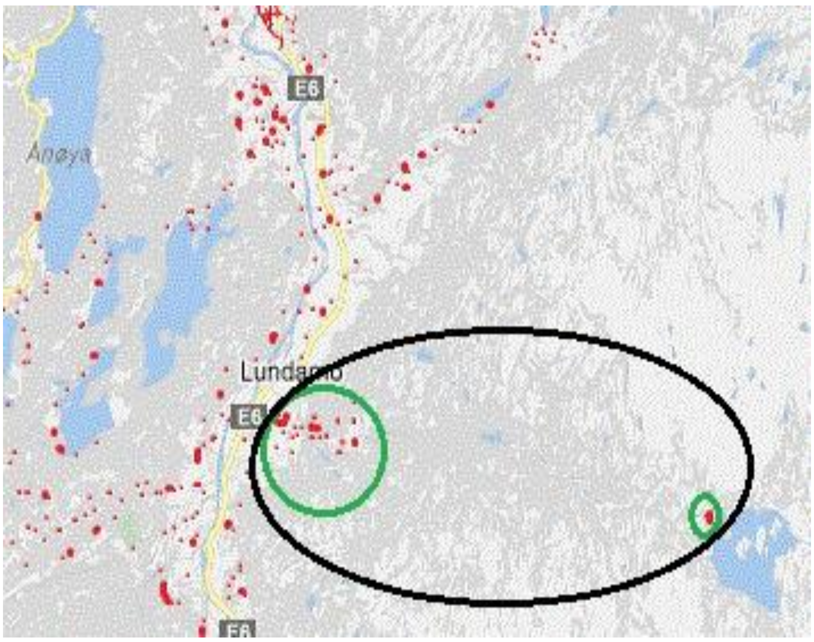

Figure 9 Method of clustering

5. Those groups of customers located round the rivers can merge into the neighboring cluster area. An illustration is shown in Figure 10; the black circle represents the cluster area.

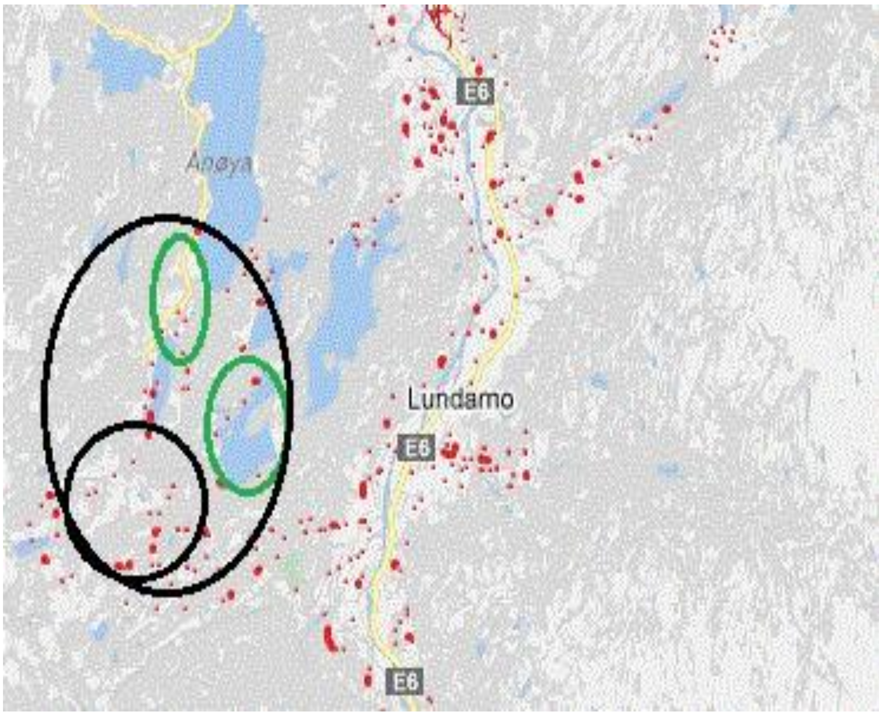

Figure 10 Method of clustering

According to the procedures mentioned above, we will be able to develop the map of Melhus with depot and cluster areas marked in Figure 11.

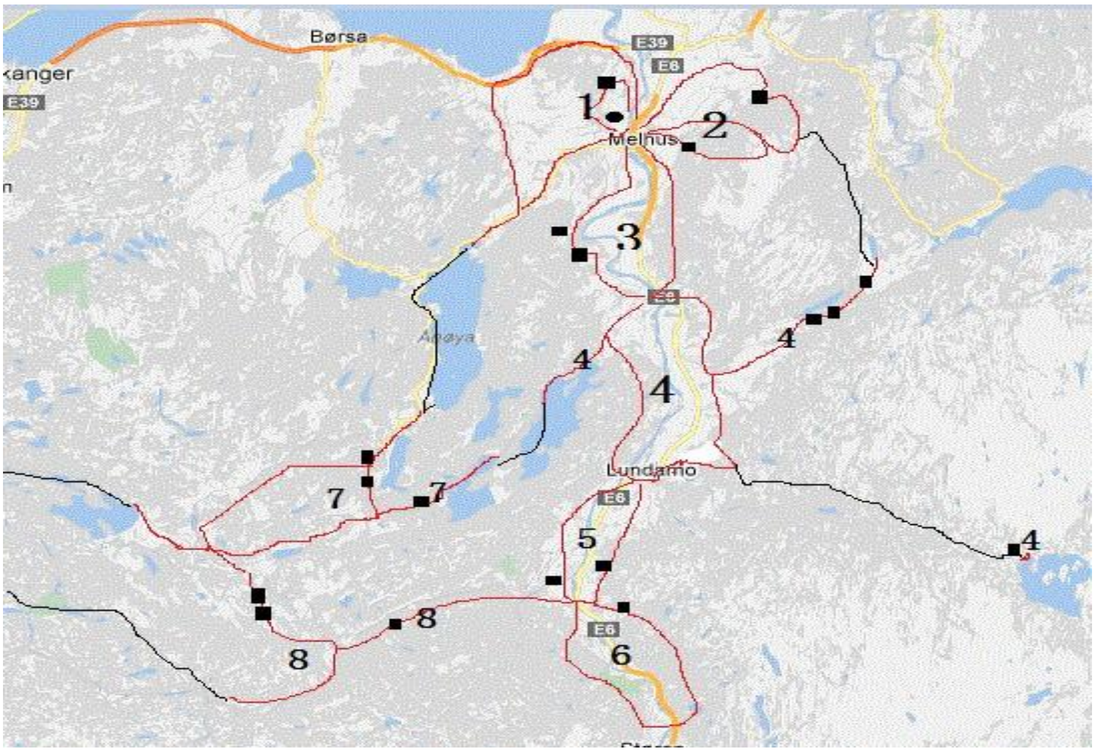

Figure 11 Map of Melhus with depot, “Tett anlegg” tanks, and cluster areas marked

The red line represents those roads surrounded by the customers required sewage collection, while the black line indicates those roads not attached with customers. And the Arabic numeral stand for the name of each cluster area, while the square indicates the location of the customers attached with “Tett anlegg” tanks

4.2 Structure of clustering

To simplify the process of calculation for the total driving distance in each cluster area, we can designate several visiting points as the only places to visit, and use the approximate total driving distance between the selected visiting point and the depot to represent the total driving distance in each cluster area.

In this section, we define those streets or roads surrounded by groups of customers as the circles or curves. To facilitate the process of selecting visiting points for each cluster area, we can classify the clusters into several types according to the structure of the cluster area.

1. Type A

If the structure of the cluster area consists of only one circle or one curve, we can define those clusters as the “Type A” clusters. We assume that the customer located at the middle of the circle or curve denotes the only visiting point in the cluster area. This assumption can be showed in Figure 12 and 13

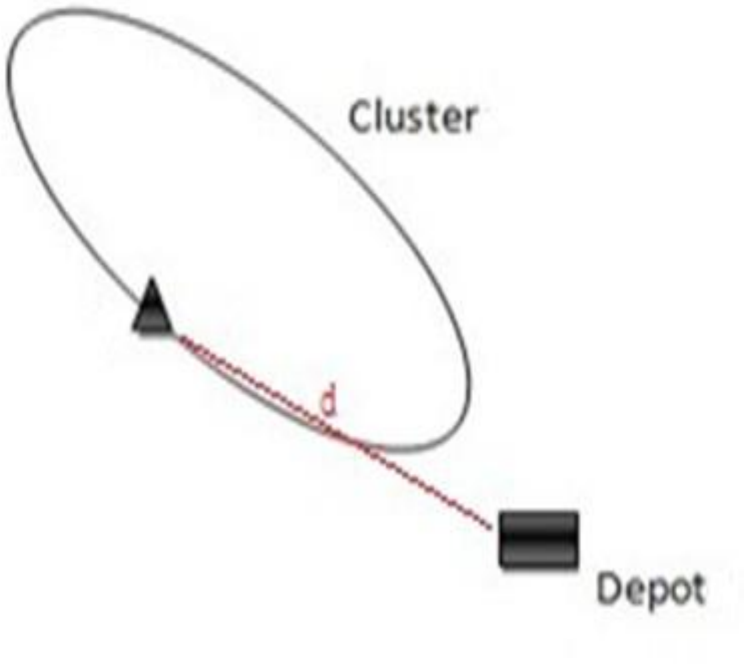

Figure 12. The structure of the “Type A” cluster area

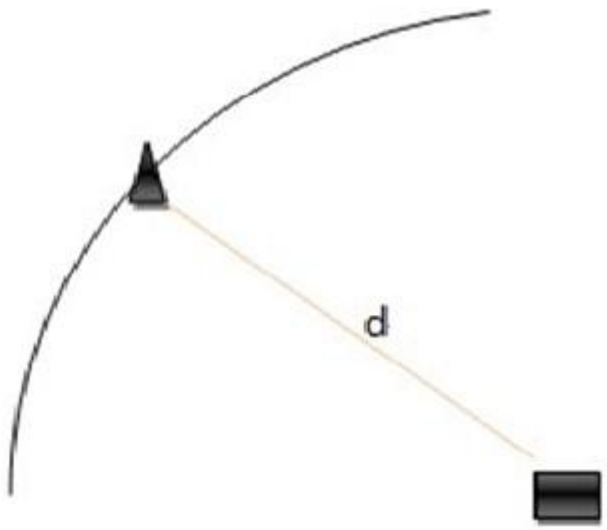

Figure 13. The structure of the “Type A” cluster area

In Figure 12 and 13, the circle or the curve indicates the clustering area, while the square and the triangle represent the depot and the visiting point respectively. “d” points out the distance between the selected visiting point and the depot.

Before we calculate the approximate total driving distance in each “Type A” cluster area, we need to make assumptions such that:

- The selected visiting point is attached with the total amount of sewage required to be collected in the cluster.
- Average distance between the depot and each customer in each cluster area is equal to the distance between the selected visiting point and the depot

Then we can use the following formulas to calculate the approximate total driving distance in each “Type A” cluster area:

Total driving distance $\sum D$ = the distance between selected visiting point and the depot $d_{i,0}$ * total number of driving tours N required in each cluster area * 2

The number of driving tours N in each cluster area can be obtained by the following formula:

Number of driving tours N = the total amount of sewage Q required to be collected in the cluster area ÷ the capacity of the truck.

2. Type B

In the following case, clusters can be classified as “Type B” cluster:

a. The structure of the cluster area consists of one circle and several curves linked to the circle.
b. The structure of the cluster area includes several nearby curves connected to each other.
c. The structure of the cluster area contains at least two circles linked to each other.

For those “Type B” clusters, we can divide the structure of the cluster area into several separated “Type A” cluster areas, and the corresponding visiting point for each “Type A” cluster area can be obtained by the method illustrated in Figure 12 and 13. Figure 14, 15a, 15b and 16 respectively show the structures of different “Type B” cluster areas, and d_i in these figures represent the distance between the selected visiting point and the depot.

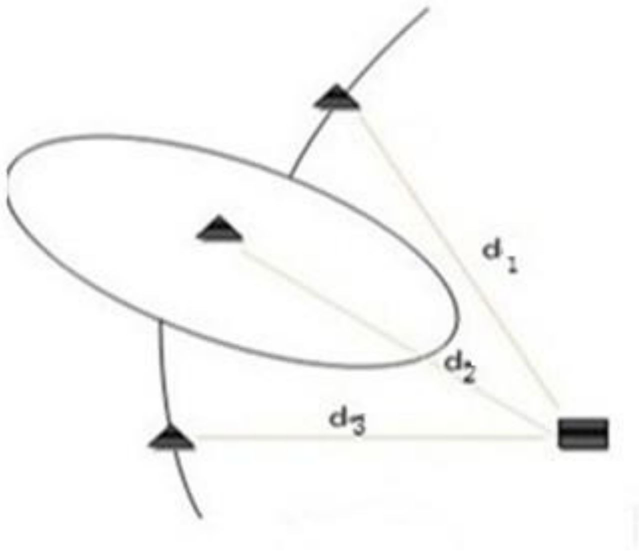

Figure 14 The structure of the "Type B" cluster area

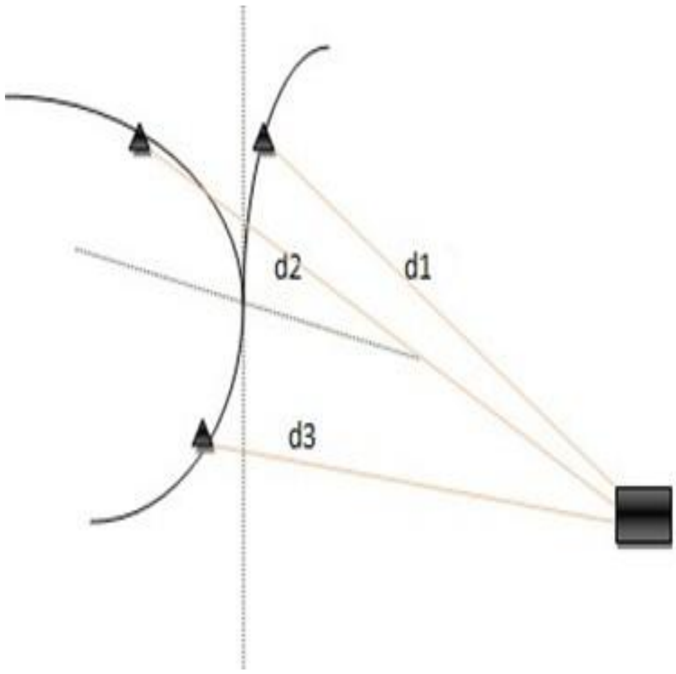

Figure 15a The structure of the "Type B" cluster area

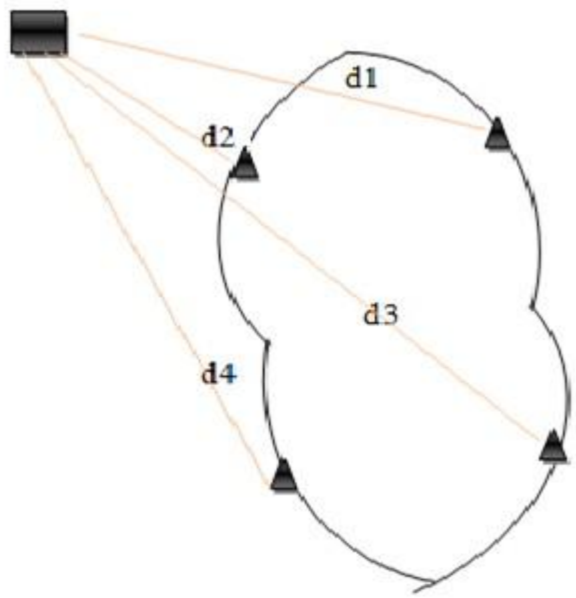

Figure 15b The structure of the “Type B” cluster area

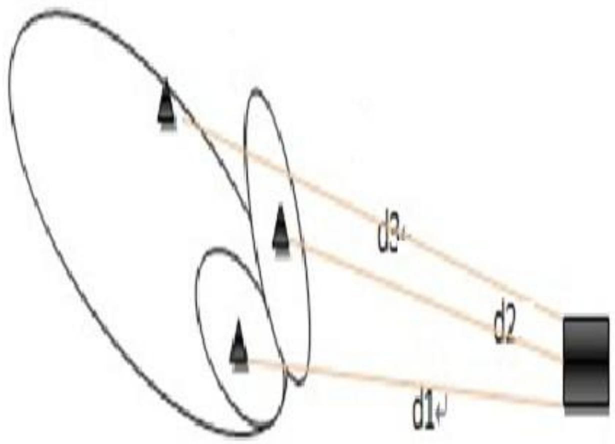

Figure 16 The structure of the “Type B” cluster area

To calculate the approximate total driving distance in each “Type B” cluster area, we also need to make assumptions such that:

- The selected visiting points are attached with the total amount of sewage required to be collected in each separated “Type A” cluster area.
- Average distance between the depot and the customer in each seperated “Type A” cluster area is equal to the distance between the selected visiting point and the depot

Then the following formulas can be used to calculate the approximate total driving distance in each “Type B” cluster area:

Total driving distance $\sum D$ = the sum of the total driving distance in each seperated "Type A" cluster area

To calculate the total driving distance in each seperated "Type A" cluster area, we can use the method discussed in the above section.

3. Type C

If the structure of the cluster area consists of one "Type A" cluster area and one visiting point far away from the "Type A" cluster area, we can define those clusters as the "Type C" cluster; an illustration is shown in Figure 17.

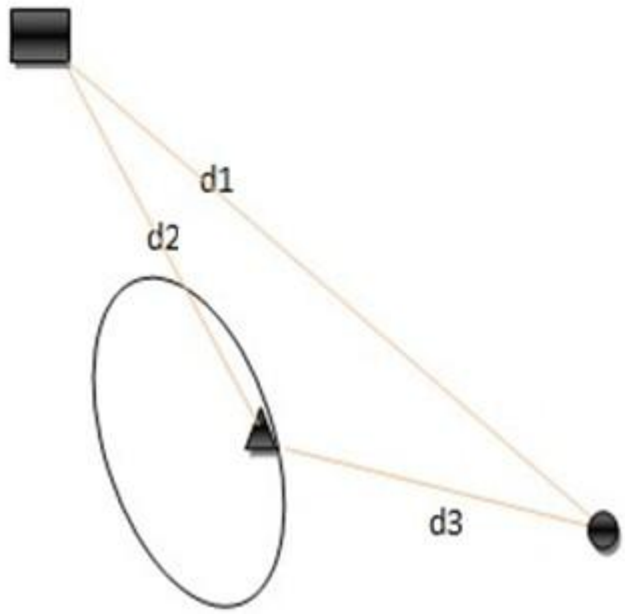

Figure 17 The structure of the "Type C" cluster area

In each "Type C" cluster area, we will assign two visiting points, which are represented by the triangle and the black spot respectively in Figure 17. The square in the figure indicates the depot, and "d1" and "d2" point out the distance between the selected visiting point and the depot, while "d3" represents the distance between two selected visiting points

To compute the approximate total driving distance in each "Type C" cluster area, assumptions need to be made such that:

- The selected visiting point in the "Type A" cluster area is attached with the total amount of sewage required to be collected in the cluster area.

Then the following formula can be used to calculate the approximate total driving distance in each “Type C” cluster area:

Total driving distance $\sum D$ = the total driving distance in the “Type A” cluster area + distance between two selected visiting points * 2

To calculate the total driving distance in the “Type A” cluster area, we can use the method discussed above.

By separating all of the clusters into three types, we will be able to develop another version of map with selected visiting points marked for each cluster area. An illustration is shown in Figure 18. The triangle represents the selected visiting points for each cluster area.

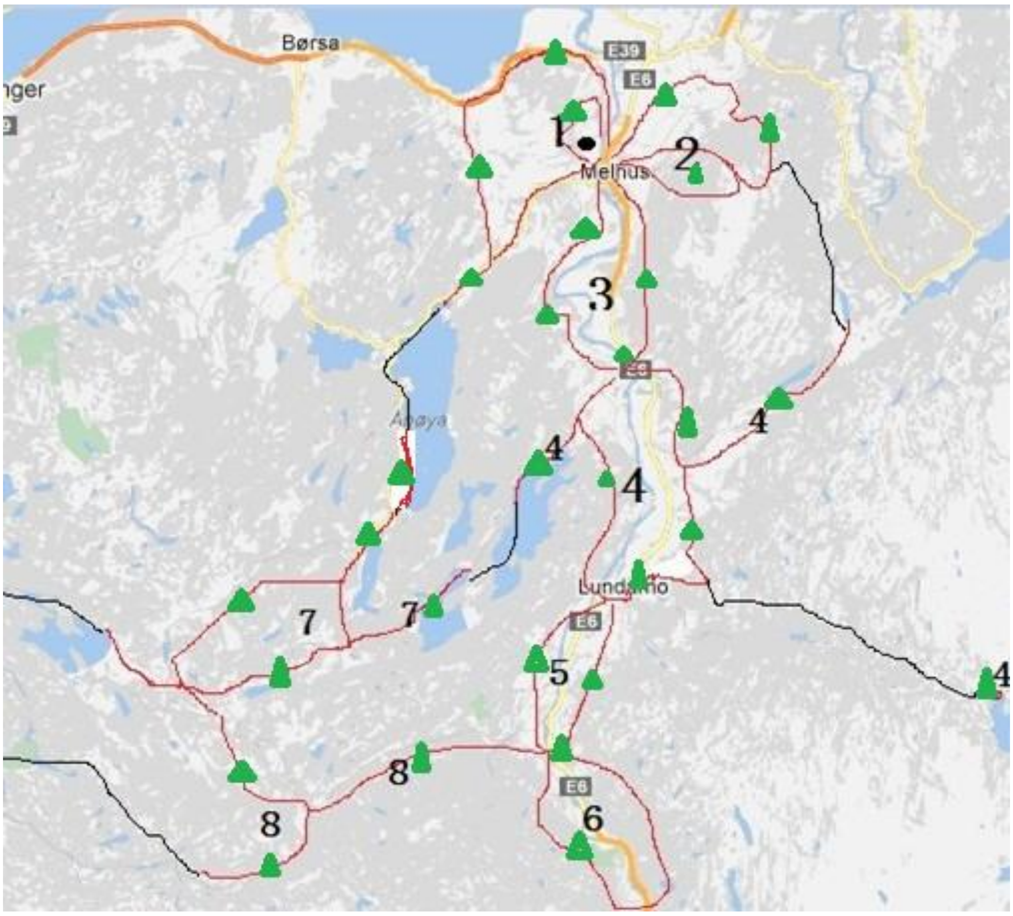

Figure 18 Clusters with selected visiting point marked

4.3 Methods to calculate the total driving distance under different logistics strategies

In this paper, we only consider two logistics strategies to perform the sewage collection service. In order to determine the appropriate strategy, calculating the approximate total driving distance under different logistics strategies is an important step. The total demand of each selected cluster every 52 weeks or 104 weeks can be obtained by sorting out the data of demand for each customer in Excel, and then based on the assumption we made to select the visiting points for each cluster area, we can easily compute the total driving distance in each cluster area when using the formula described in the above section. And the total driving distance is equal to the sum of the total driving distance in each cluster area.

When performing the strategy using both dewater truck and traditional truck to serve the customer, because those “Tett anlegg” tanks should be cleaned up by traditional truck, then we need to allocate the traditional truck in each cluster area to serve those “Tett anlegg” customers as well as the nearby customers until all of the “Tett anlegg” tanks are cleaned up. For the rest of the customers, it is arbitrary to to use the traditional or dewater truck to visit. The corresponding total driving distance in this case is not difficult to calculate, which is equal to the sum of the total distance driven by the traditional truck plus the sum of the total distance driven by the dewater truck, the relevant formula is presented as follows:

Total driving distance $\sum D$ = Total driving distance when using traditional truck $\sum D1$+Total driving distance when using dewater truck $\sum D2$

5. Computational results

In Melhus, during a two-year period, the demand of each selected visiting point in the first year is different from that in the second year. Thus, we need to calculate the total driving distance under different logistics strategies for the first and the second year respectively in order to determine the ideal strategy. By setting the formulas described above in Excel, we will be able to compute the result of the total driving distance under different strategies in different years.

Table 1 and 2 respectively show the results of the total driving distance when using only traditional truck or using both types of truck to serve the customer for the first year, 2013.

Table 1 Results of the total driving distance when using only traditional truck to serve the customer for the first year

Cluster	Visiting point	Demand in one year	Capacity	Distance per tour	Total distance
1	102860	217.50	30	4.28	62.12
	101893	111.00		8.07	59.72
	101908	123.00		5.34	43.78
	101992	40.50		4.74	12.81
	102051	165.50		6.11	67.36
2	102661	326.00		4.15	90.13
	102732	228.50		8.20	124.84
	102809	38.50		4.49	11.52
3	102024	339.00		5.38	121.52
	102214	439.60		10.97	321.45
	102397	185.50		9.18	113.50
	177444	176.00		4.91	57.62
4	102279	110.00		12.19	89.39
	102348	335.00		13.13	293.34
	103684	325.00		19.89	430.97
	183745	5.00		36.34	12.11
	103541	256.00		15.74	268.65
	102958	477.50		15.44	491.39
	102868	160.00		12.78	136.37
	102997	492.50		18.96	622.52
5	197194	233.50		23.97	373.21
	103964	432.50		25.35	730.95
	123141	221.00		21.57	317.78
6	103833	384.50		26.95	690.81
7	103509	31.00		17.06	35.26
	103462	109.50		19.27	140.69
	103119	79.50		22.83	120.98
	103418	247.50		26.44	436.20
	173253	217.00		23.50	339.97
8	103254	605.00		33.80	1363.28
	103395	71.50		34.29	163.46
	103944	157.00		32.00	334.91
					8478.60

Table 2 Results of the total driving distance when using both traditional truck and dewater truck to serve the customer for the first year

Cluster	Visiting point	Demand	Capacity	Distance per tour	Extra distance	Total distance
1	102860	217.5	250 or 30	4.28	75.00	490.01
	101893	111		8.07	75.00	
	101908	123		5.34	75.00	
	101992	40.5		4.74	75.00	
	102051	165.5		6.11	75.00	
2	102661	326		4.15	75.00	285.45
	102732	228.5		8.20	75.00	
	102809	38.5		4.49	75.00	
3	102024	339		5.38	75.00	443.31
	102214	439.6		10.97	75.00	
	102397	185.5		9.18	75.00	
	177444	176		4.91	75.00	
4	102279	110		12.19	75.00	1319.84
	102348	335		13.13	75.00	
	103684	325		19.89	75.00	
	183745	5		36.34		
	103541	256		15.74	75.00	
	102958	477.5		15.44	75.00	
	102868	160		12.78	75.00	
	102997	492.5		18.96	75.00	
5	197194	233.5		23.97	75.00	595.41
	103964	432.5		25.35	75.00	
	123141	221		21.57	75.00	
6	103833	384.5		26.95	75.00	198.25
7	103509	31		17.06	75.00	430.60
	103462	109.5		19.27	75.00	
	103119	79.5		22.83	75.00	
	103418	247.5		26.44	75.00	
	173253	217		23.50	75.00	
8	103254	605		33.80	75.00	576.44
	103395	71.5		34.29	75.00	
	103944	157		32.00	75.00	
Total						4339.30

The first column in the table indicates the marked number of the cluster area, which is shown in Figure 11, while the second column shows the ID-number for each selected visiting point. And the third column represents the demand of sewage for each selected visiting point, while “Distance per tour” is the distance between the selected visiting point and the depot. The total driving distance in each cluster area is shown in the last column. The 7th column in Table 2 indicates the extra driving distance for each tour when using dewatering truck.

In the second year, the total demand in each cluster area decreases significantly compared with that in the first year. To reduce the driving cost, it is possible to drive several tours, passing through two cluster areas, and then the associated approximate driving distance per tour for one way is equal to the distance between two cluster areas plus the distance between the depot and the selected visiting point. Table 3 and 4 respectively show the result of the total driving distance under different strategies for the second year 2014

Table 3 Results of the total driving distance when using only one traditional truck to serve the customer for the second year

Cluster	Visiting point	Demand	Capacity	Distance per tour	No. of tours	Total distance for each seperated cluster
1	102860	116.5	30	4.28	3.88	34.27
	101893	45	30	8.0697	1.50	65.84
	101908	51.5	30	5.3393	1.72	
	101992	6	30	5.12	2.70	252.60
	102051	75.5	30			
2	102661	183	30	4.1472	6.10	49.77
	102732	128	30	8.1954	4.27	84.42
	102809	13	30		0.43	
3	102024	160	30	5.3768	5.33	57.35
	102214	72.5	30	10.9686	2.42	53.01
	102397	52.5	30	9.1779	1.75	32.12
	177444	67.5	30	4.9108	2.25	22.10
4	102279	24.5	30	12.19	0.82	19.91
	102348	88	30	13.1346	2.93	77.06
	103684	129	30.00	19.89	4.30	189.85
	183745	5				
	103541	79	30	15.7411	2.63	82.90
	102958	156	30	15.4362	5.20	160.54
	102868	20.5	30	12.7846	0.68	17.47
	102997	145.5	30	18.9601	4.85	183.91
5	197194	49.5	30	23.9749	1.65	79.12
	103964	86.5	30	25.351	2.88	146.19
	123141	54	30	21.5687	1.80	77.65
6	103833	54.5	30	26.9496	1.82	97.92
7	103509	9	30	17.0605	0.30	77.17
	103462	41.5	30	19.2723	1.38	
	103119	15.5	30	22.8256	0.52	23.59
	103418	63.5	30	26.4365	2.12	111.91
	173253	49	30	23.5004	1.63	76.77
8	103254	178	30	33.8003	5.93	401.10
	103395	40.5	30	34.2924	1.35	92.59
	103944	48	30	31.9977	1.60	102.39
Total					76.75	2669.51

Table 4 Results of the total driving distance when using both traditional truck and dewater truck to serve the customer for the second year

Cluster	Visiting point	Demand	Capacity	Distance per tour	No. of tours	Total distanc
1	102860	116.50	250.00	4.28	3	141.00
	101893	45.00		8.07		
	101908	51.50		30.01		
	101992	6.00				
	102051	75.50				
2	102661	183.00	250.00	4.15	3	127
	102732	128.00		8.20		
	102809	13.00				
3	102024	160.00	250.00	5.38	4	139.45
	102214	72.50		10.97		
	102397	52.50		9.18		
	177444	67.50		4.91		
4	102279	24.50	250.00	13.13	4	271.31
	102348	88.00				
	103684	129.00		19.89		
	183745	5.00				
	103541	79.00		15.74		
	102958	156.00		15.44	3	219.63
	102868	20.50		12.78		
	102997	145.50		18.96		
5	197194	49.50	250.00	23.97	4	285.81
	103964	86.50		25.35		
	123141	54.00		21.57		
6	103833	54.50	250.00	26.95		
7	103509	9.00	250.00	17.06	3	297.19
	103462	41.50		19.27		
	103119	15.50		22.83		
	103418	63.50		26.44		
	173253	49.00		23.50		
8	103254	178.00	250.00	33.80		
	103395	40.50		34.29		
	103944	48.00		32.00		
Total						1481.39

5.1 Comparison of the total driving distance under different logistics strategies

According to Table 1 and 2, we will be able to make the comparison of the total driving distance under different logistics strategies for the first year. The comparison is shown in Table 5.

Table 5 Comparison of the total driving distance under different strategies for the first year

Cluster	Visiting point	Freq.	T1	T2	D1	D2
1	102860	104 weeks	7	3	245.79	490.01
	101893		4			
	101908		4			
	101992		1			
	102051		6			
2	102661		11	2	226.49	285.45
	102732		8			
	102809		1			
3	102024		11	4	614.09	443.31
	102214		15			
	102397		6			
	177444		6			
4	102279		4	14	2344.74	1319.84
	102348		11			
	103684		11			
	183745		0			
	103541		9			
	102958		16			
	102868		5			
	102997		16			
5	197194		8	6	1421.94	595.41
	103964		14			
	123141		7			
6	103833		13	2	690.81	198.25
7	103509		1	4	1073.10	430.60
	103462		4			
	103119		3			
	103418		8			
	173253		7			
8	103254		20	3	1861.65	576.44
	103395		2			
	103944		5			
Total			245	38	8478.60	4339.30

When performing the strategy using both traditional truck and dewater truck, we can use the dewater truck to visit several selected visiting points on one tour in order to reduce the total driving distance. The third column shows the frequency to serve the customer, which is every 104 weeks. And T1 indicates the approximate number of tours required to drive by using only traditional truck for serving each selected visiting point, while T2 represents the approximate number of tours required to drive by using both traditional truck and dewater truck within each cluster area. D1 is the total driving distance within each cluster area when using only traditional truck to serve the customer, while D2 represents the total driving distance when using both traditional truck and dewater truck.

Table 5 clearly shows that, when using only traditional truck to serve the customer, the total driving distance is around 8378 km, approximately 2 times of the total driving distance under the strategy using both traditional truck and dewater truck.

When we look into the table in details, it is evident that, within the cluster “1” and “2” area, to use only traditional truck to serve the customer is much cheaper than using both types of truck, since D1 is lower than D2 in row one and row two. Then in cluster “1” and “2” area, we can just allocate traditional truck to serve the customer. For the rest of the cluster areas, it is preferable to use both types of truck, since it can reduce the total driving distance compared with the other strategy using only traditional truck.

Table 6 shows the comparison of the total driving distance under different strategies for the second year.

Table 6 Comparison of the total driving distance under different strategies for the second year

Cluster	Visiting point	Freq.	Demand	T1	T2	D1	D2
1	102860	54 weeks	116.5	3.88	3	352.71	141.00
	101893		45	1.50			
	101908		51.5	1.72			
	101992		6	2.70			
	102051		75.5				
2	102661		183	6.10	3	134.19	127
	102732		128	4.27			
	102809		13	0.43			
3	102024		160	5.33	4	164.59	139.45
	102214		72.5	2.42			
	102397		52.5	1.75			
	177444		67.5	2.25			
4	102279		24.5	0.82	4	369.72	271.31
	102348		88	2.93			
	103684		129	4.30			
	183745		5				
	103541		79	2.63			
	102958		156	5.20	3	361.92	219.63
	102868		20.5	0.68			
	102997		145.5	4.85			
5	197194		49.5	1.65	4	400.87	285.81
	103964		86.5	2.88			
	123141		54	1.80			
6	103833		54.5	1.82			
7	103509		9	0.30	3	885.51	297.19
	103462		41.5	1.38			
	103119		15.5	0.52			
	103418		63.5	2.12			
	173253		49	1.63			
8	103254		178	5.93			
	103395		40.5	1.35			
	103944		48	1.60			
Total				76.75	24	2669.51	1481.39

For some nearby cluster areas with low demand, e.g. cluster area marked with “5” and “6”, to drive several tours passing through these cluster areas is possible.

When looking at the result of the total driving distance D1and D2 in each cluster area, we can see that the strategy using only traditional truck to serve the customer is poorer than the other strategy using both types of truck, because the total driving distance in each cluster area is larger.

6. Conclusions

In this paper, we have identified the proper logitics stragety for sewage collection in Melhus. In section 5, we have shown that the strategy using both types of truck to serve the customer is superior to the other stragety using only traditional truck.

Since the total amount of emission of pollution gas produced by vehicles and the total driving cost are proportional to the corresponding total driving distance, then the total driving cost and total amount of emission under the strategy using both types of truck is definitely lower than the other strategy using only traditional truck.

When performing the strategy using both types of truck, we also need to consider the allocation of vehicles for serving different cluster of customers during a two-year period. Table 7 shows the allocation of different vehicles for serving each cluster area in the first year. In the table, T1 indicates the approximate number of tours required to drive in each cluster area when using only traditional truck for serving each selected cluster of customers, while T2 represents the approximate number of tours required to drive when using both traditional truck and dewater truck. D1 is the total driving distance in each selected cluster area when using only traditional truck, while D2 represents the total driving distance when using both traditional truck and dewater truck.

In the last column, A indicates the strategy of allocation of vehicles in each cluster area. For instance, in the second row, the strategy "V1" means that we should use traditional truck to serve those customers in cluster "1" area since the total driving distance D1 in this row is lower than D2, while in the third row, the strategy "V1&V2" means that to allocate both types of truck to serve the customer in the cluster "3" area is much cheaper than the other strategy "V1", since the corresponding total driving distance D2 is lower.

An illustration of allocation of vehicles when performing the strategy using both types of truck to serve the customer for the second year is shown in Table 8.

Table 7 Solution of allocation of vehciles for the first year when performing the strategy using both types of truck

Cluster	Freq.	T1	T2	D1	D2	A
1	104 weeks	22	3	245.79	490.01	V1
2		20	2	226.49	285.45	V1
3		38	4	614.09	443.31	V1&V2
4		72	14	2344.74	1319.84	V1&V2
5		30	6	1421.94	595.41	V1&V2
6		13	2	690.81	198.25	V1&V2
7		23	4	1073.10	430.60	V1&V2
8		28	3	1861.65	576.44	V1&V2
Total		245	38	8478.60	4339.30	

Table 8 Solution of allocation of vehciles for the second year when performing the strategy using both types of truck

Cluster	Freq.	T1	T2	D1	D2	A
1		10	3	352.71	141.00	V1&V2
2		11	3	134.19	127	V1&V2
3		12	4	164.59	139.45	V1&V2
4	54 weeks	22	7	731.00	490.00	V1&V2
5		8	4	400.87	285.81	V1&V2
6						
7		15	3	885.51	297.19	V1&V2
8						
Total		77	24	2668.87	1480.45	

6.1 Further research

In this paper, sewage collection problem is a typical waste collection problem, and can be treated as a CVRP. Obviously, the sewage collection problem is NP-hard (Karp, 1972). To improve the quality of our solution, we can find a better approach to develop the cluster of customers, and, secondly, propose several heuristics to detemine the optimal set of routes performed by a given set of heterogeneous vehicles in order to obtain good solution to identify the proper logistics strategy.

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